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ABSTRACT

The aims of this project were to explore the challenges faced by Scottish primary teachers in implementing the science and technology aspects of the Environmental Studies guidelines, to illuminate the extent to which any problems might be related to their own understanding of those ideas they were expected to teach, and to assess the extent to which initial and inservice training were adequately providing for the development of primary techers' understanding of science and technology. The study included a questionnaire survey of 514 primary teachers, interviews with a sub-sample of these teachers, discussion of records kept by teachers, and interviews with teacher educators. Important findings include: many teachers found that discussing the science in everyday events helped their own understanding, many teachers feel that they have not been adequately trained to teach science, confidence was higher in relation to teaching processes than concepts, practical examples of technology were more easily recognized than the technological concepts involved, teachers asked for a range of different forms of help, and initial education courses do not cover much of the science content teachers need to teach. Implications for management, teachers, policymakers and teacher educators are also discussed. (JRH)

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No 34

Primary Teachers' Understanding of Concepts in Science and Technology

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Primary Teachers' Understanding of Concepts in Science and Technology

Wynne Harlen and Colin Holroyd

The Scottish Council for Research in Education

In anticipation of the publication, in March 1993, of the National Guidelines for Environmental Studies within the 5–14 programme, The Scottish Office Education and Industry Department (SOEID) commissioned a research project to study the implications for primary teachers of implementing the guidelines, the difficulties they might encounter and the help that may be needed. The research was carried out by independent researchers at the Scottish Council for Research in Education from March 1993 to February 1995. The study included: a questionnaire survey of 514 primary teachers, in which they gave their views of their confidence in teaching in the various subject areas and in particular aspects of science and technology; interviews with a sub-sample of these teachers through which information was gained about their understanding of some concepts in science and technology; discussion of records kept by teachers of topics and activities covered; and information gathered by interviews with college and local authority staff about initial and in-service primary teacher education in science and technology.

Aims and research questions

The *Environmental Studies* guidelines include a structure for the development of knowledge, understanding and skills in (amongst other things) science and technology. This structure specifies for the first time those areas of science and technology in which pupils should develop understanding: these are, for science, *Living Things and the Processes of Life, Energy and Forces, Earth and Space* and, for technology, *Technology in Society* and *The Design Process.*

The aims of the project were to explore the challenges faced by Scottish primary teachers in implementing the science and technology aspects of the guidelines and in particular to illuminate the extent to which any problems might be related to their own understanding of those ideas they were expected to teach. A further aim was to assess the extent to which initial and in-service training were adequately providing for the development of primary teachers' understanding of science and technology. However, although teachers need understanding related to the content of the curriculum, this is not the only knowledge necessary for teaching. Thus, whilst the project's focus was on understanding of concepts of science and technology, this was firmly within a context of other knowledge relating to teaching, to the curriculum and to the characteristics of learners.

Analysis of the aims of the research led to a series of research questions. In this summary these are condensed to four:

- How confident are primary teachers that they can help pupils to achieve the 5–14 attainment outcomes in science and technology?
- To what extent do teachers understand key features of the attainment outcomes in science and technology?
- What difficulties do teachers experience in practice in teaching science and technology?
- What changes in initial teacher training, and in other forms of help, are likely to improve primary teachers' confidence, understanding and practice in teaching science and technology?

How information was collected

There were four phases of information gathering. For the most part these can be related to the four questions above, but information relevant to one question was often collected in more than one phase.

Phase 1 A questionnaire was sent to P3, P4, P6 and P7 teachers in the schools taking part in the 1993 Assessment of Achievement Programme (AAP) survey of attainment in science. The questionnaire asked for some background information about the teachers' gender, experience and training and length of service. It also asked teachers to say how confident they felt about teaching various aspects of the curriculum and about helping pupils to achieve certain skills, knowledge and understanding indicated in a selection of the 'key features' for science and technology in the guidelines. The way in which the schools were sampled and the high response rate (replies were received from 83% of schools sampled) mean that the results are representative of primary teachers in Scotland as a whole.

Phase 2 This phase involved in-depth interviews with a P6 and a P7 teacher from 30 schools. These teachers were selected from the questionnaire sample to provide a range of levels of confidence in a wide variety of types of school. The interview probed understanding of the 'big ideas' of science and technology involved in six situations which were presented to teachers with the help of simple equipment and photographs. Each teacher was interviewed about three of these situations, so that about 30 responses were obtained for each one.

Many teachers found that discussing the science in everyday events helped their own understanding.

Would this be a useful form of in-service? How would the most useful topics be selected?

The interviews were designed to be as interesting and non-threatening as possible; the aim was to gain information about what teachers understood, without making them feel that they were being tested. In each science topic the teacher was asked to say what s/he observed and then to join with the interviewer in a collaborative explanation of the observations. At the end of this, teachers were asked to reflect on how, if at all, their understanding had changed during the discussion and how easy or difficult they would find it to develop understanding of the same ideas in young learners. Added to each science 'event', there was a practical problem in an area of technology that was loosely related to the science topic (but which did not imply that technology was necessarily or simply the application of science). Each technology problem was related to one or more of the key feature statements for technology that had been included in the Phase 1 questionnaire.

Phase 3 In this phase, 33 teachers from 20 Phase 2 schools kept notes of their actual science and technology teaching over a ten-week period. Forms were provided to structure the records and the teachers were then interviewed by telephone. The forms and the interviews focused on (a) topics, themes and activities covered and (b) successes and difficulties encountered in teaching and the reasons for these.

Phase 4 The five institutions in Scotland which provide initial training for primary teachers were visited and a total of 30 members of staff were

interviewed about both pre-service and in-service courses in science and technology. Documents relating to these courses were analysed. In addition, interviews were carried out with selected education authority staff providing professional development support for teachers in their regions.

Findings

Confidence

Of the 514 teachers who responded to the Phase 1 questionnaire, 92% were female, 65% had been teaching for 12 years or more and 39% had at least one Ordinary or Standard Grade award in a science subject. When asked to rate their confidence in teaching various areas of the curriculum, 41% gave the lowest rating (either 'I need help to develop my knowledge and skills in this area' or 'I can manage but depend on advice from others') to science and 60% did so for technology. The figures for mathematics and English were both 1%. For English and mathematics, 71% said they were fully confident, while 12% gave this answer for science and 6% for technology. When ratings were combined to rank subject areas in terms of confidence, technology was ranked the lowest, just ahead of information technology, music and science.

Many teachers feel they have not been adequately trained to teach science.

What can be done to raise the confidence of those currently teaching, assuming improved teacher education for future teachers?

When asked about specific content and contexts for science and technology, teachers were reasonably confident that they had the knowledge needed to develop pupils' understanding of *Living Things and the Processes of Life*, but even here one-third of teachers said they needed significant amounts of help. Confidence about *Earth and Space* key features was roughly the same as for *Living Things and the Processes of Life*, but there was considerable variation from one key feature to another. For *Energy and Forces* confidence was lower, with more than half of the teachers wanting significant amounts of advice and help. Confidence about having the knowledge to develop understanding in pupils of technology was even lower than for science; it was somewhat higher for social aspects of technology than for control technology and design technology. Confidence in developing science skills and processes in pupils was greater than confidence in developing understanding of science content.

Technology was an area where teachers felt least confidence.

How can adequate teaching be achieved?

The questionnaire also asked about the difficulty experienced in relation to certain professional skills such as matching activities to pupils' development, using questioning skills, record keeping and organising and supporting practical work. Teachers reported least difficulty in introducing a new topic and ensuring the equal interest of boys and girls, and most difficulty in diagnostic assessment of conceptual development and process skills.

With regard to science and technology teaching, male teachers were more confident than female teachers; more recently qualified teachers were more confident than more experienced teachers; teachers who had some science qualifications in their own educational backgrounds were more confident than those who had none.

Confidence was higher in relation to teaching processes than concepts.

Will the 5-14 guidelines help teachers to balance process and concepts?

Data gathered in Phases 2 and 3 of the project showed that many teachers possessed a high degree of *general professional knowledge* which allowed them to tackle science and technology teaching with some confidence; however, many of these teachers were still not confident that their own understanding would be adequate to help conceptual development in their pupils.

Understanding of science

Each of the 'events' used in the interviews related to one of the key features indicated in the national guidelines. In structuring the interviews the researchers identified the 'big ideas' which underpinned each key feature statement; these ideas indicated the conceptual understanding that would be promoted in pupils by studying the content of the key feature.

It was found that there were some 'big ideas' which were either already understood or in which understanding was developed in working with the interviewer, whilst others were difficult for teachers to understand at all. For example one big science idea, that the differences observed in fish were helpful in the different environments in which the fish lived, was securely understood by every teacher with no assistance. On the other hand the idea that it is easier for light energy from the sun to get in through the glass of a greenhouse (or through carbon dioxide in the atmosphere) than it is for heat energy to get back out again, was only understood by one teacher without assistance and only by a further eight after discussion.

The 'big science ideas' studied in the research can be divided into three groups:

(i) Ideas that are commonly understood by teachers, eg

- Water exists as solid, liquid or gas.
- Bones move at joints because of muscles.

Most teachers know, or can quickly develop understanding of, more science than they realise.

(ii) Ideas that are less commonly understood, but in which understanding is readily developed, eg

- To see an object, light from it has to enter the eye.
- Muscles pull, but don't push.

What is the best way of unlocking this understanding?

(iii) Ideas that are not commonly understood and in which understanding is difficult or time-consuming to develop, eg

- The battery supplies electrical energy, which the bulb changes into heat/light energy.
- Evolution occurs over time, because of the selection of those inherited differences which are helpful for survival.

Individual teachers varied widely in the level of their understanding of the science ideas. One teacher clearly understood most of the ideas at the start of the discussion and all of them at the end; another showed understanding of less than half of the ideas, even after working with the interviewer.

Many teachers held misunderstandings of the ideas they are expected to develop in pupils. The types of misunderstanding included: using a name for a phenomenon as if it were an explanation of it; giving an inappropriate analogy; attributing properties that do not correspond with reality; proposing a mechanism for which there is no evidence; equating everyday language with scientific language and believing that 'some' means 'all'.

Teachers have to understand scientific ideas if they are to help pupils develop them.

Teachers who had done some science in secondary school beyond S2 tended to have better understanding of science ideas than those with no science in their own background. At the same time there were some teachers with no science in their background who had managed to gain a good understanding of the big science ideas.

What knowledge and understanding do you think teachers need?

Understanding of technology

Several themes emerged from the discussions about the technological problems discussed in Phase 2. Teachers were often unclear about the nature and purposes of technology education in the primary school. The *Environmental Studies* guidelines made technology look difficult, but when teachers saw examples of the key features in action they recognised them as familiar types of classroom activities and found the meaning of the statements to be simpler than expected. Examples of control technology were often familiar to teachers, even when the terminology was not. For example, one of the technology problems involved a picture from a children's book showing a simple robotic arm. Comparison was invited between the robotic arm and a human arm and particularly about whether the robotic arm could be made to pick up a small object as can a human arm. There was little difficulty in confirming that the robotic arm could be 'programmed' to do this, although few teachers recognised this as control technology or indicated that some form of sensor would be needed to detect the object to be picked up. However, in the context of another task, related to pollution from power stations, most teachers recognised that it was necessary to have a monitoring device to detect pollutant levels before action could be taken to control them.

Practical examples of technology were more readily recogised than the technological concepts involved.

In general teachers appeared to feel more at ease in discussing tasks relating to design, such as how to help senior citizens use mirrors to see the back of their heads, or how to improve the design of a simple rain gauge. Many had an intuitive grasp of technology derived from the common-sense of everyday experience. However, in the classroom enjoyable practical construction activities were often assumed to be technology and the importance of using these as a vehicle for developing technological ideas was not always appreciated.

How are the ideas of technology best communicated so that teachers are able to use them?

Science and technology in the classroom

In Phase 3 teachers had been asked to note successes and difficulties and since it was mostly through attention to difficulties that ways of helping could be explored, it is inevitable that these tend to be given attention, although there was

undoubtedly some valuable and successful teaching going on. All of the teachers involved in Phase 3 taught a fair amount of science during the period in which they kept notes for the research study. About half chose science and technology work which linked into wider environmental studies topics (for example, Homes, World War II, Space Exploration, the European Community, Healthy Living, the Vikings, Oil, Rivers). In other cases the science and technology topics were self-contained, with titles like Energy, Electricity, Magnetism, Cold-water Chemistry, Water, Vehicles. The technology teaching tended to focus on construction activities rather than on the design process. There was little control technology and only occasionally were science and technology fruitfully linked. The topics and themes that were taught were usually based on the personal decisions of individual teachers rather than on a whole-school policy or plan.

The most frequently cited source of problems was equipment/materials. Equipment was said to be unreliable, insufficient, difficult to obtain, store and access, with little or no guidance on what to do if things went wrong. Written materials were said to be not readily available, insufficiently differentiated, and thin on the background knowledge required. Other causes of difficulties were: finding time for preparation, safe management of pupils when some were doing practical work, lack of physical space and inadequate classroom facilities.

About a third of the teachers identified their own lack of background knowledge as a source of problems. They lacked the necessary knowledge and understanding either to respond to children's questions or to resolve situations where experiments failed to give the expected answers or equipment broke down.

Teachers mentioned that, although pupils enjoyed the physically active part of science, they found talking, reflecting, evaluating and recording more difficult. Teachers reported that girls found physical science and technology less engaging than did boys.

Despite problems, most teachers were satisfied with the science and technology that they taught. However, the criteria on which they based their satisfaction were not usually centred on conceptual development in their pupils. It was also evident that teachers adopted ways of teaching which made best use of their general teaching skills whilst avoiding situations where their confidence was low. The strategies reported included:

- compensating for doing less of a low-confidence aspect of science or technology by doing more of a higher confidence aspect: in science: this might mean stressing the process aims in science rather than the concept development aims and doing more biology/nature study and less physical science; in technology it meant spending more time on construction work and less on design; more on social aspects and less on control technology
- heavy reliance on kits, prescriptive texts and pupil work-cards
- emphasis on expository teaching and underplaying discussion
- over-dependence on standard responses (such as 'good question – how would you find the answer?') to content-related questions.

Some teachers restricted pupils' opportunities to those aspects of science and technology where they felt most confident.

Does this apply to you? What are the implications for pupils' knowledge and understanding and their progression?

Professional development needs

It was clear that teachers were working hard to 'cope' despite the fact that their education and training had not equipped them with personal understanding across the range of content in the 5–14 guidelines. But the survival skills they adopted for 'coping' resulted too often in a restricted experience of science and technology. This finding adds urgency to the question of what forms of help are needed and how they can be supplied.

The types of help needed which teachers identified could be grouped under the headings of: in-service courses; print-based resources; time to think and prepare; more and improved equipment; a school policy on what to teach and when; advice from specialists, and improvement in coordination and support within the school. By far the greatest number of requests were for in-service training but strong opinions were expressed about what form this should take. Teachers had firm views on the kind of course needed, as the following comments indicate:

Teachers asked for a range of different forms of help, including training.

What is the best use of limited time and resources for training?

> *The courses are never long enough to do what you want them to do. You can instil a bit of confidence, but really, what can anyone do with someone like me in five hours? One day's training – can't say it's not beneficial, but it's short and sweet, it couldn't explore a weakness thoroughly.*
>
> *In-service would be good, so that you're actually doing the experiments, finding the difficulties. It shouldn't be one-off, it shouldn't be voluntary or after-school – it has to be a regional thing for all schools and has to be so many times a year.*

It was also clear that there were aspects of teaching — such as introducing and managing practical investigations, assessment and recording — with which help was needed with aspects other than understanding the subject matter, suggesting caution in assuming that lack of confidence in teaching certain aspects or ideas will be improved by increasing background knowledge.

Initial and in-service teacher education

The review of time given to science and technology in the initial education of primary teachers found that contact hours in a PGCE course could be as low as 16. Within the BEd there were only about 90 hours over four years and in one teacher education institution (TEI) it was very much lower. The amount of science and technology teaching experience on school placement varied very widely: for some students the amount was zero.

Initial education courses do not cover much of the science content teachers need to teach.

Do all primary teachers need science to the same level? Could some be trained to help others?

The emphasis on *content* (ie on student teachers' conceptual understanding in science and technology) had recently started to increase and this was likely to continue — but there was considerable opposition to the pendulum swinging too far away from *process*. Much of the 5–14 science and technology content was not covered in initial training; tutors hoped student teachers would come to understand these areas by their own self-directed learning. Scientific and technological understanding was catered for within optional courses in the BEd. In recent years some options have been cancelled because too few students had enrolled for something they thought might be difficult for them.

The science background of applicants had not influenced the selection of students in the past but it was starting to have an influence. There was a growing opinion that science should be as important as English and mathematics in student selection.

A few short in-service courses were provided by TEIs but most short courses and other forms of teacher support were provided by Education Authorities, who were planning for a large increase in demand as the implementation of *Environmental Studies* became a priority. Short courses tended not to address issues of teachers' understanding but concentrated on providing suggestions for classroom activities.

There may well be a huge demand for courses in science and technology.

What should be the balance of attention to process and content in these courses?

The Postgraduate Certificate in Environmental Studies continued to be offered in five TEIs and increased demand was expected. The Postgraduate Certificate in Primary Science Teaching flourished in one centre and had recently started in a second; it is essentially about the management of science in the school as a whole and within classrooms. Two other certificate course were at the planning stage and were aimed at science and technology coordinators who would help the implementation of 5-14 in their schools. There was increased recognition in most of these courses that there was a need to enhance teacher understanding of the concepts of science.

Final Report

Further details of the study are in the full report — *Confidence and Understanding in Teaching Science and Technology in Primary Schools* — available from the Scottish Council for Research in Education,15 St John Street, Edinburgh EH8 8JR. Price £17.00.

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The views expressed in this paper are those of the authors and do not necessarily reflect those of The Scottish Office Education and Industry Department who funded the study.

Implications

The findings of the project have implications for all those involved in facilitating science and technology education in primary schools.

Implications for headteachers and school management teams

- To produce and keep under review a whole-school policy for science and technology, taking into account the national guidelines for Environmental Studies.
- To plan and co-ordinate the provision of school-based or cluster-based professional development activities, making use of external agencies as appropriate.
- To appoint from within the staff subject co-ordinators with responsibilities for science and technology.
- To ensure the acquisition and accessible storage of adequate learning resources and equipment.
- To facilitate, whenever possible, the provision of technician/auxiliary help to support the teaching of science and technology.
- To arrange opportunities for sharing problems and solutions in teaching science and technology and encouraging the development of confidence.

Implications for teachers

- To re-examine the balance in their work between practical activity and discussion with pupils of the meaning of their findings.
- To reflect critically on the extent to which it is necessary to develop their own understanding and attempt to find opportunity for that development.
- To recognise that no-one is able to answer all pupils' questions and that this is not in any case desirable, but that they can develop skills of using all pupils' questions productively.

Implications for policy-makers at national and local authority levels

- To provide support, particularly for the training of support co-ordinators, on the scale needed to alleviate the current situation which restricts pupils' scientific and technological development.
- To use findings of research into teachers' misunderstandings to target in-service and other help where it is most needed.
- To continue and extend the production of print-based and other materials to support teaching, and which include background information at the teachers' level.
- To re-examine the role of specialism in primary school curriculum delivery.
- To review the Memorandum on Entry Requirements and the Guidelines for Teacher Training in relation to the qualifications and the selection of candidates for primary training.

Implications for teacher educators

- To ensure that there is sufficient time available for science and technology within initial training to prepare student teachers to teach 5-14 effectively.
- To review the relative priority to be attached to content and process aims within initial training to teach science and technology in the primary schools.
- To review course content in relation to catering for conceptual change in both the education of teachers and the teaching of pupils.
- To examine the selection procedures for entry to primary training, particularly with regard to the qualifications in science subjects that applicants should possess.

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